

Top-Down Decarbonization

EES 3310/5310

Global Climate Change

Jonathan Gilligan

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Considerations on Projections of Future Emissions

Grain of Salt

- Implied decarbonization rates depend on predictions of P , G , etc.
- Predicting population and economic growth are very tricky and imprecise.
- So take any of these calculations with a grain of salt.
- But are they still useful, despite the uncertainties?

Implied Decarbonization for Green New Deal

Kaya Identity

$$F = P \times g \times e \times f$$

- F = emissions (million metric tons (MMT) CO₂ per year)
- P = population (billions)
- g = per-capita GDP (\$1000 per person)
- e = energy intensity of economy (quads / \$ trillion)
 - Reducing e means increasing **energy efficiency**
- f = carbon intensity of energy supply (MMT CO₂ / quad)
 - Reducing f means **replacing fossil fuels** with cleaner energy

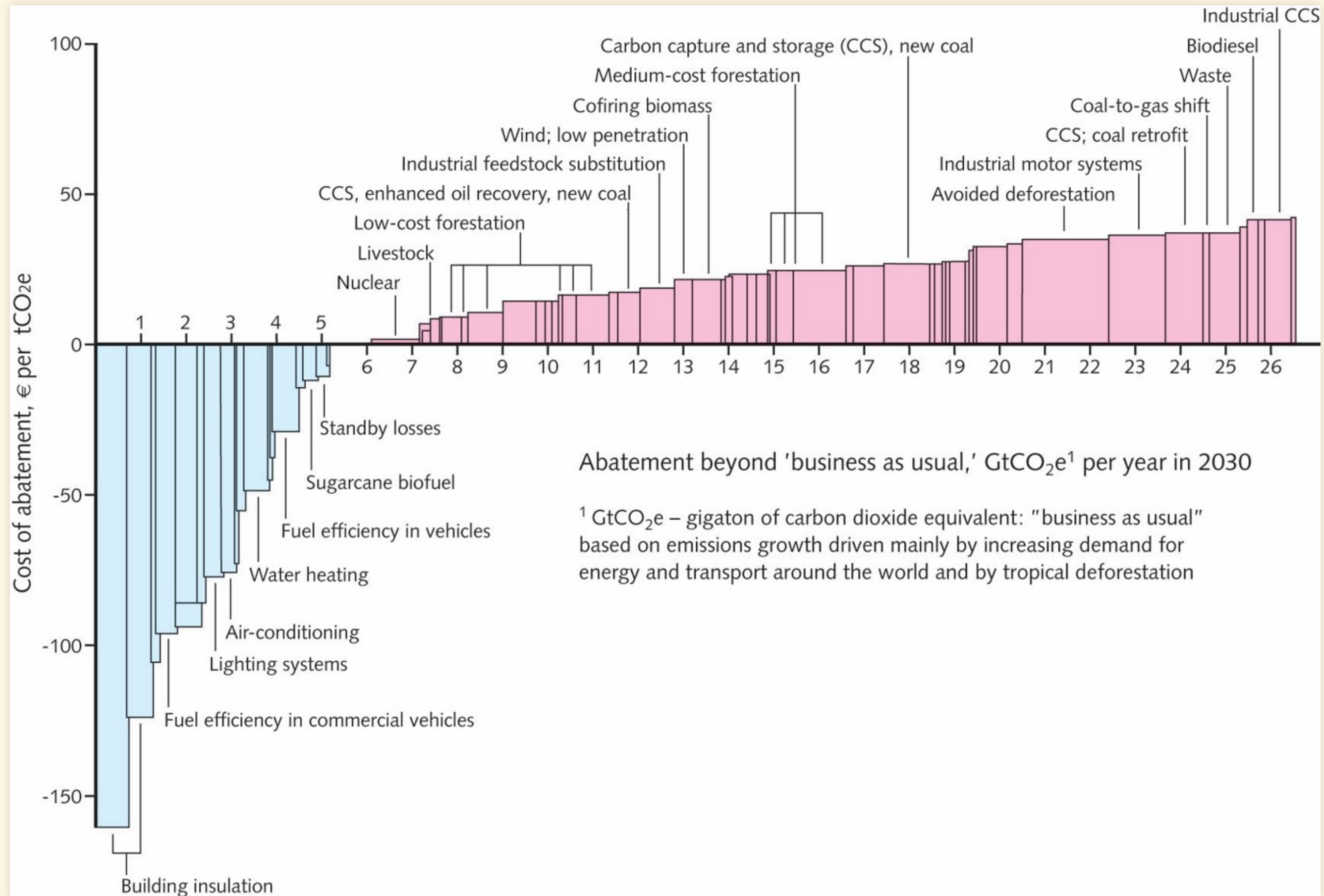
US Green New Deal

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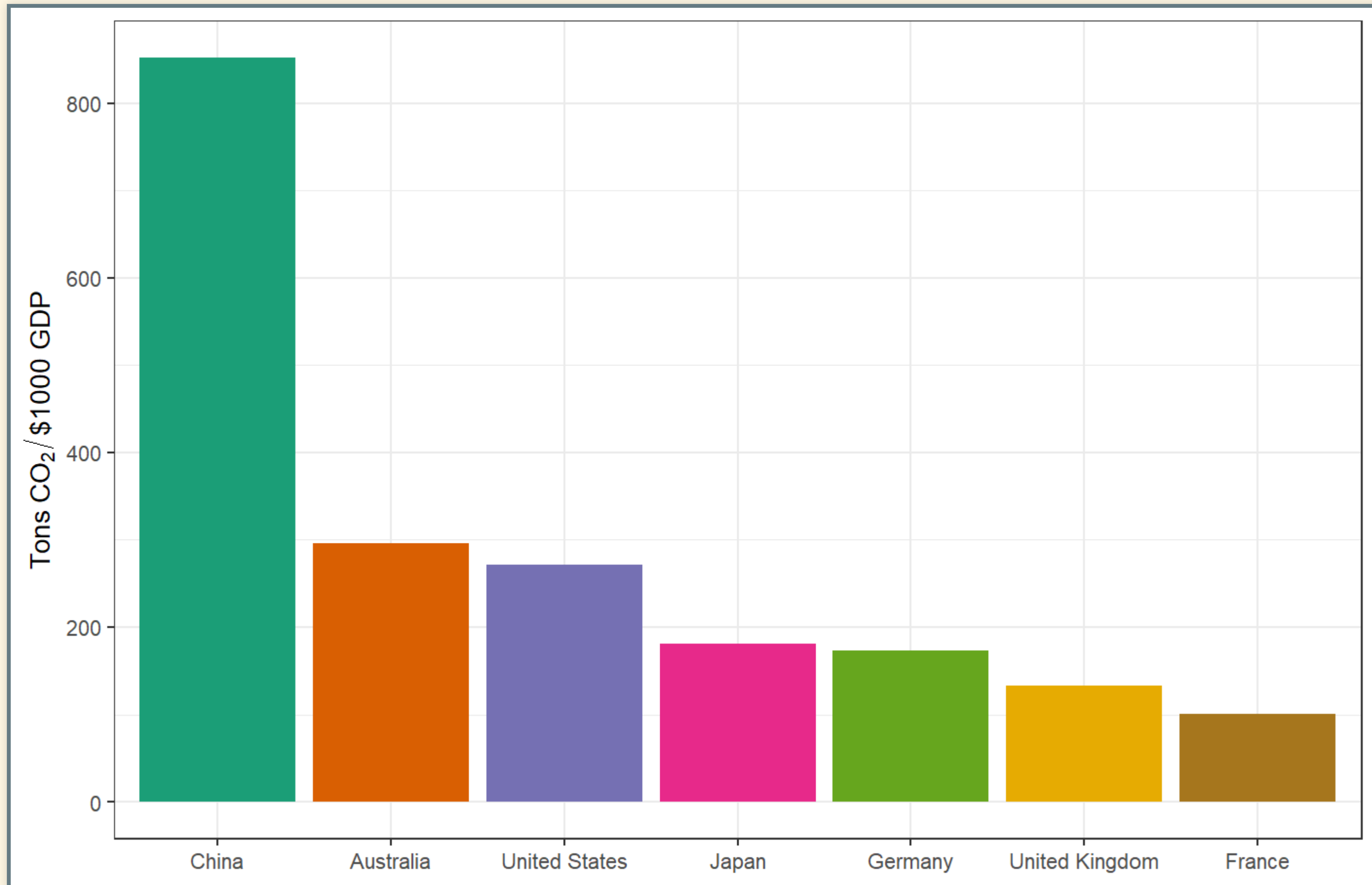
- The Green New Deal has many definitions:
 - Resolution in Congress does not give specific emissions targets.
 - Bernie Sanders campaigned on a promise to completely eliminate CO₂ emissions by 2050 and reduce them 71% by 2030
 - $F(2030) = 1484$ MMT
 - $F(2019) = 4965$ MMT
 - Could we do this in 11 years?
 - We would have to cut ef by 13.4% per year.
 - Historically, since 1990, ef has dropped 2.5% per year.

How Can We Decarbonize?

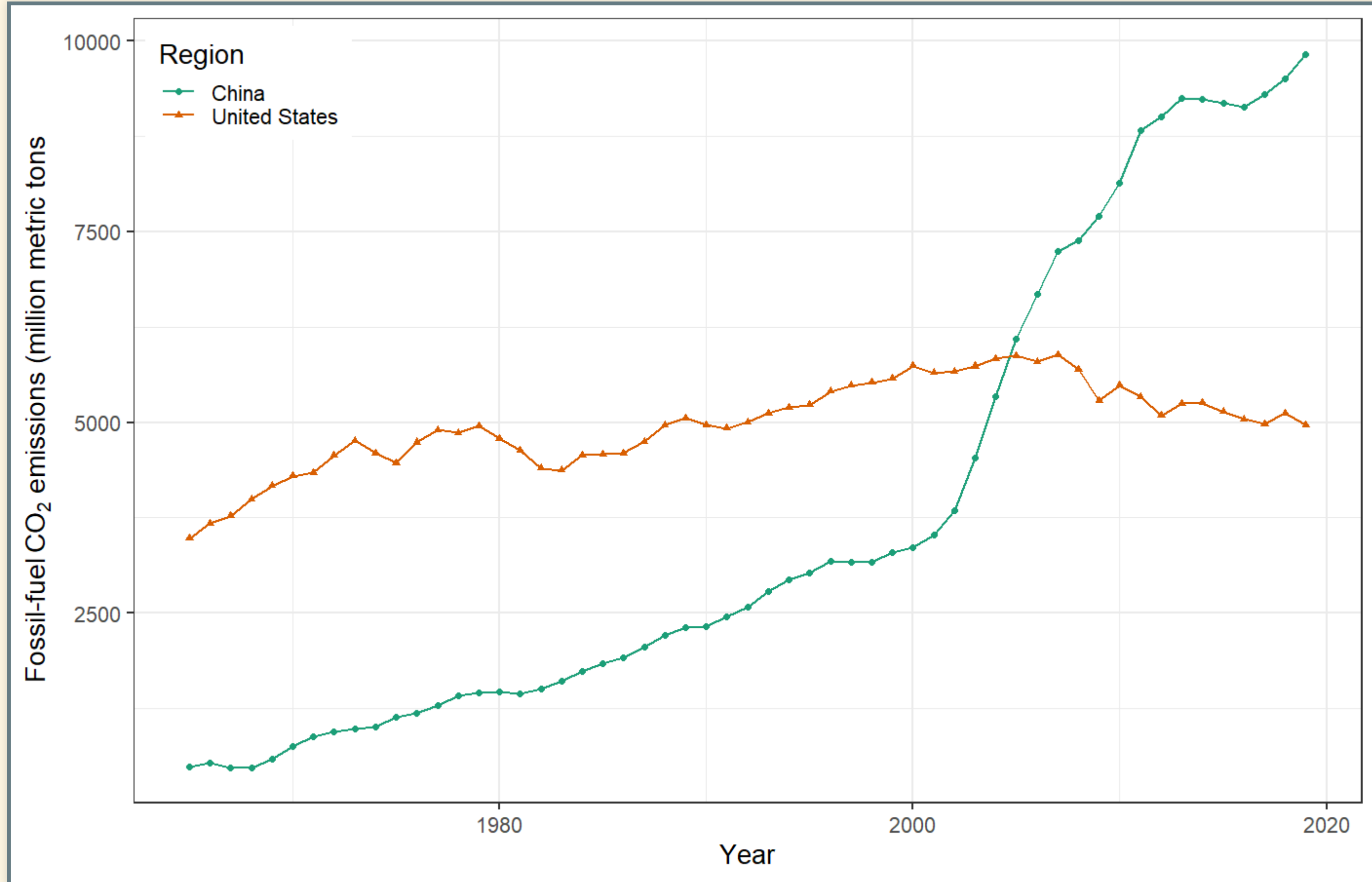
Detailed Abatement Options



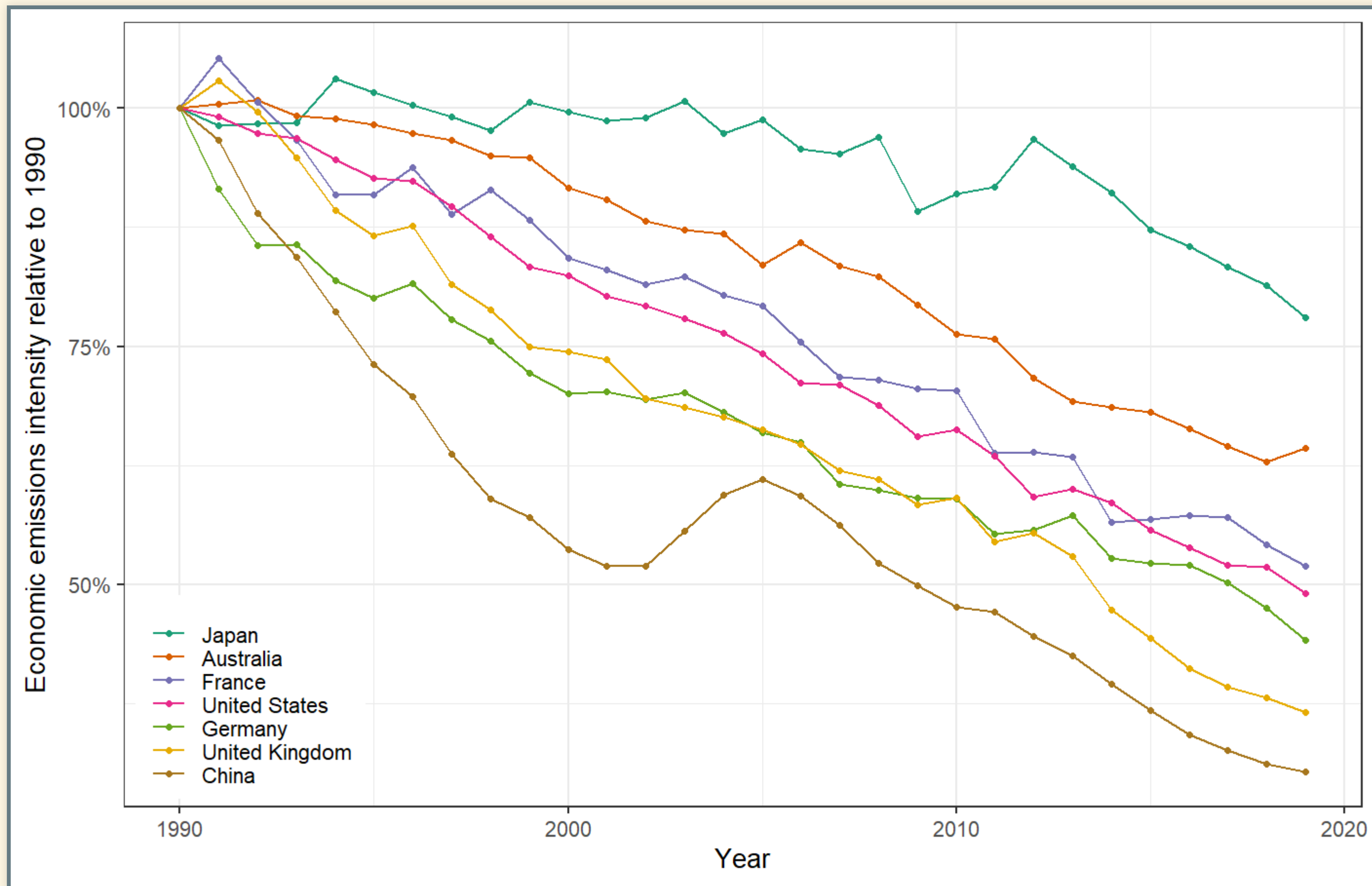
Economic Carbon Intensity in 2019



CO₂ Emissions 1965–2019



Relative improvement in carbon intensity 1990–2019



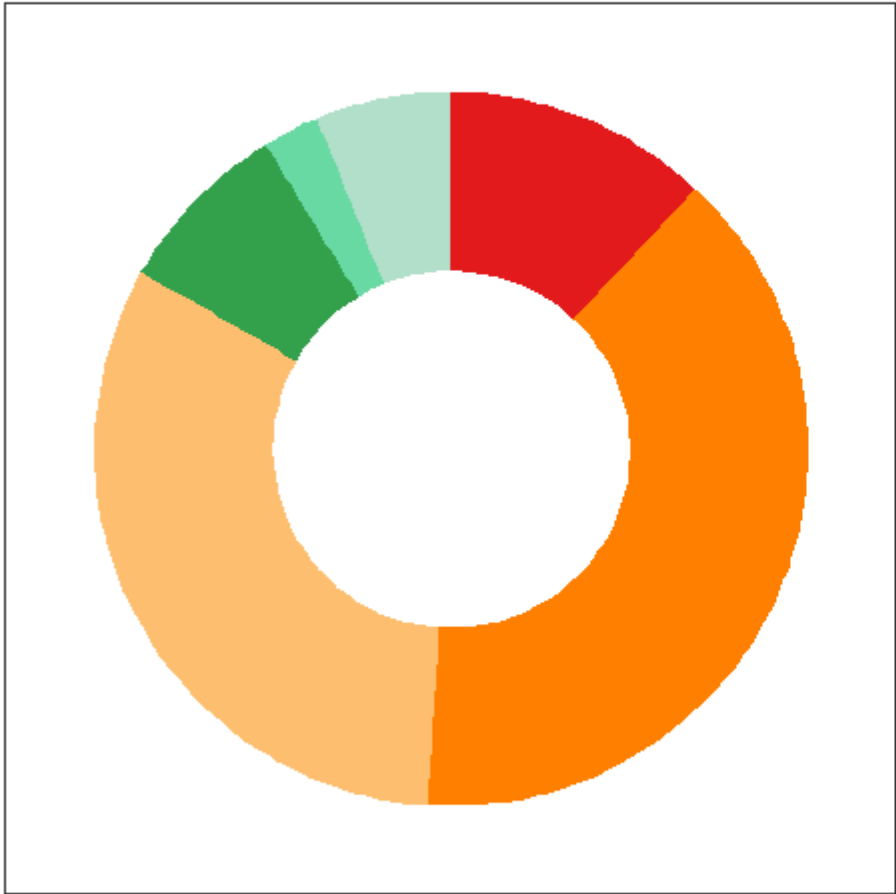
Top-Down Analysis for Green New Deal

Projected Energy Use in 2030

- Energy Information Administration top-down projection for energy demand in United States in 2030:
 - Total 2030 Primary Energy Use = 88.8 Quads
 - Assume P , g , and e are fixed.
 - Manage emissions by reducing f
 - Switch from fossil fuels to clean energy

Energy Mix in 2019

United States



Fuel

- Coal: 10.75 quads (12.0%)
- Oil: 35.06 quads (39.1%)
- Natural Gas: 28.89 quads (32.2%)
- Nuclear: 7.2 quads (8.0%)
- Hydro: 2.29 quads (2.6%)
- Renewables: 5.52 quads (6.2%)

Fuel	Quads	%
Coal	10.7	12
Oil	35.1	39
Natural Gas	28.9	32
Nuclear	7.2	8
Hydro	2.3	3
Renewables	5.5	6
Total	89.7	100

Emissions Factors

Fuel	MMT CO ₂ per Quad
Coal	94
Oil	70
Natural Gas	53
Nuclear	0
Hydro	0
Renewables	0

Projected Business as Usual Emissions in 2030

Fuel	%	Quads	MMT/Quad	MMT CO ₂
Coal	12	10.6	94	1004
Oil	39	34.7	70	2428
Natural Gas	32	28.6	53	1518
Nuclear	8	7.1	0	0
Hydro	3	2.3	0	0
Renewables	6	5.5	0	0
Total	100	88.8	NA	4951

Top-down emissions-reduction

Fuel	%	Quads	MMT/Quad	MMT CO ₂
Coal	12	10.6	94	1004
Oil	39	34.7	70	2428
Natural Gas	32	28.6	53	1518
Nuclear	8	7.1	0	0
Hydro	3	2.3	0	0
Renewables	6	5.5	0	0
Total	100	88.8	NA	4951

- Projected emissions for 2030 = 4951 MMT
 - If f doesn't change.
- Emissions goal for 2030 = 1484 MMT
- Must cut by $(4951 - 1484) = 3467$ MMT
- Start with coal:
 - Cut 1004 MMT (10.64 quads)
 - 2463 MMT left
- Next, cut gas:
 - Cut 1518 MMT (28.59 quads)
 - 945 MMT left
- Finally, cut oil:
 - Cut 945 MMT (13.49 quads)
- Total energy cuts = $10.64 + 28.59 + 13.49 = 52.72$ quads.

Clean Energy Sources

- 11,000 megawatts (MW) for one year = 1 quad
 - (See Climate Fix, p. 97)
- **Nuclear Power Plant:**
 - $1000 \text{ MW} \times 75\% \text{ capacity factor} = \mathbf{750 \text{ MW average}}$
 - $1 \text{ quad per year} = 11,000 \text{ MW} / (750 \text{ MW per nuclear plant})$
 $= \mathbf{14.7 \text{ nuclear plants}}$
- **Solar Photovoltaic:**
 - $30 \text{ MW} \times 30\% \text{ capacity factor} = \mathbf{9 \text{ MW average}}$
 - $1 \text{ quad} = \mathbf{1,200 \text{ photovoltaic solar farms}}$
- **Wind Turbine:**
 - $6 \text{ MW} \times 42\% \text{ capacity factor} = \mathbf{3 \text{ MW average}}$
 - $1 \text{ quad} = \mathbf{4,400 \text{ wind turbines}}$

Meeting Green New Deal Goal

- Cut CO₂ by 3467 MMT
 - 1004 MMT from coal (10.6 quad)
 - 1518 MMT from gas (28.6 quad)
 - 945 MMT from oil (13.5 quad)
- Total clean energy needed: quads per year
- 53 quads × 15 nuclear plants/quad =
770 nuclear power plants in 11 years
(70 per year)
- 53 quads × 1,200 photovoltaic solar farms/quad =
63,000 photovoltaic solar farms in 11 years
(6,000 per year, or 100 per week)
- 53 quads × 4,400 wind plants/quad =
232,000 wind turbines in 11 years
(21,000 per year, or 60 per day)

Pielke's Bottom Line

- Unfeasible to build so much clean energy so quickly
- Expense of building so much clean energy would defeat economic goals
- This is why we don't have the technology to decarbonize as quickly as politicians and activists have been promising.

But ...

- Renewable energy is getting cheaper very quickly
- It may soon be profitable to shut down existing fossil-fuel power plants and replace them with renewables.

Review

Bottom-Up Analysis

- Start with individual Kaya-identity variables:
 - P, g, e, f
 - Figure out historical rates of change for each
- Gross Domestic Product: $G = P \times g$
 - Rate of change of G : $r_G = r_P + r_g$
 - Rate of change of a product is the sum of the rates of change of the factors.
 - Use rate of change of G to extrapolate G in the future

Bottom-Up Analysis

- Start with individual Kaya-identity variables
- Start with the policy goal: change in F .
 - Figure out implied rate of change of emissions r_F .
- Compare to the expected rate of change of GDP r_G .
- Calculate the implied rate of decarbonizing the economy, r_{ef} :

$$r_{ef} = r_F - r_G$$

- Compare implied r_{ef} to the historical trend in ef to assess the difficulty of meeting the policy goals.

Top-Down Analysis

- Start with macroeconomic estimate of future energy demand E
- Use mix of energy sources and emissions factors to calculate future emissions (F) if the mix of energy sources does not change.
- Your policy has a goal for F
- Calculate difference between projected future F and policy goal for F .
- Calculate how many **quads of fossil-fuel energy** you would have to replace with clean energy to meet the policy goal.
 - Start with cutting coal, then cut natural gas, and finally cut oil
 - Why?
- Figure out how many power plants of different kinds you would have to build to supply the necessary clean energy.